



EUROPEAN PATENT APPLICATION

27 Application number: 88310280.8

21 Int. Cl.<sup>4</sup> H02K 37/14

22 Date of filing: 01.11.88

30 Priority: 02.11.87 US 116374

32 Date of publication of application:  
10.05.89 Bulletin 89/19

34 Designated Contracting States:  
AT BE CH DE ES FR GB GR IT LI LU NL SE

71 Applicant: SEAGATE TECHNOLOGY, INC.  
920 Disc Drive  
Scotts Valley California 95068(US)

72 Inventor: Heine, Gunther Karl  
143 Driftwood Court  
Aptos California 95003(US)  
Inventor: Klein, Enrique Jorge  
1686 Christina Drive  
Los Altos California 94022(US)  
Inventor: Kuwert, Oswald  
161 Provincetown Court  
Aptos California 95003(US)  
Inventor: Seeger, Bernhard Michael  
1609 Taylor Lane  
Santa Cruz California 95062(US)

74 Representative: Bayliss, Geoffrey Cyril et al  
BOULT, WADE & TENNANT 27 Finsbury Street  
London EC4A 1PQ(GB)

36 Encapsulated stepper motor.

27 A single-housing stepper motor is disclosed comprising a rotor (14) and stator (16) both mounted in a single housing (10) (which may be a part of the base casting) the bearings (40, 42) supporting the rotor for rotation within the housing both being located on the rotor shaft on the same side of the rotor adjacent one another, the opposite end of the single housing being covered with a sealed plastic cover (44). The lamination stack (18) that forms the stator is piloted by machined surfaces (30, 32) into a high tolerance fit within the housing (10), and clamped in place with a simple wave washer/snap ring combination (66, 68). The stator laminations are designed with a decagonally interrupted periphery which can be used without changing the area of the poles (20), and allow space for the wires to the poles to be lead out past the lamination stack. A sealing plastic cover (44) is provided with a special pressure finger (60) to hold the wires (36) running to the stator coils away from the sharp edges of the stack wave spring and snap ring; the cover is also specially designed to

capture the wires to relieve the strain on the wires. Alternatively (Fig. 5), the bearings (104, 106) may be located on opposite sides of the rotor (14), the stator (16) is piloted into a precisely aligned position on an inner wall of the housing adjacent the front bearing (104), the other end of the stack being held in place by a bearing holder (116) interposed between the rear bearing (106) and the edge of the stator (16), the holding forces being precisely defined to accurately align the stator with the rotor of the stepper motor. The entire assembly, including the rear bearing, bearing holder and stator support, as well as the stator is held together with a star-shaped spring (15) comprising a plurality of fingers (106A-D) that slide into and rotate within slots (158A-D) in the housing in a bayonet arrangement. These slots allow insertion of the star-shaped spring under pressure, and rotation under pressure within the groove (160) to a seated position. The same groove then accepts the (160) to a seated position. The same groove then accepts the encapsulating plastic cover (170), prefer-

ably inserted through the same openings as the bayonet arms of the spring, though being rotated in the opposite direction.

## ENCAPSULATED STEPPER MOTOR

This invention is especially useful in a disc drive of the type described in U.S. Application Serial No. 914,690 filed October 2, 1986, and incorporated herein by reference.

This invention relates generally to stepper motors, and more particularly to a stepper motor designed for use in a disc drive.

Stepper motors designed to rotate through a predetermined angle upon application of a pulse of current are well known. Such stepping motors are useful in fields where positive, accurate, discrete movements reliably responsive to high frequency pulses are desired. Applications involving frequent repositioning of a mechanical member to successively different positions are ideally adapted for the use of a stepper motor. Thus, stepper motors are commonly used in disc drives to position the head carrying actuator relative to the information storage disc. Pulsed instructions are converted directly to accurate mechanical motions by the stepping motor.

Typical stepping motor construction involves a plurality of rotor poles, a number of stator poles, and a number of coils for generating a magnetic field. The magnetic field produces forces that tend to bring the rotor poles into alignment with the particular stator poles which form the lowest reluctance configuration. The phases are pulsed sequentially to bring each rotor-stator combination from non-alignment into an aligned configuration, thereby rotating the shaft to which the rotors' poles are commonly joined.

The construction of stepper motors has heretofore been complicated and expensive. The provision of a large number of poles introduces problems to conventional construction methods. Often the poles are formed as teeth on a gear, requiring expensive machining. A large number of tedious steps customarily are necessary to assemble the pole pieces and connect them with the support structure, the shaft, and the like. The stack of laminations used to form the stator must be precisely aligned in a narrow tolerance relationship with the rotor, with the stator pieces being captured between two end bells which are used to hold the components together. Achieving the required parallelism of the stack of laminations, the rotor and the concentricity of front and rear end bells is very difficult under these precise tolerance conditions. Accurate alignment is frequently compromised by irregularities in the stack of laminations, and by differences in tension when tightening the screws which hold the end bells together. Since the two end bells each hold a shaft support bearing, any

misalignment can skew the rotor relative to the stack. Also, the end bells are separately machined and may have tolerance differences, resulting in a lack of concentricity in the assembled motor.

Further, in the event some defect occurs in the assembly of a stepping motor, it is extremely difficult to disassemble and rework the motor in an economically efficient fashion.

Thus, the market demands greater speed; increased accuracy in positioning the transducer over the target track; and lower power consumption in the stepper motor. This can best be achieved by optimizing the rotor/stator tooth geometry and dimensioning with improved tolerance compliance. It can also be achieved by increasing the magnetic force between the rotor and stator. The problem presented is to achieve this not by increasing the coil current, but by decreasing the gap between the rotor and the stator. The solution to this problem lies in improved control of rotor and stator fabrication, and the provision of better means for maintaining parallelism between the rotor and stator in the stepper motor, while reducing cost.

It is an objective of this invention to provide a stepper motor design that can be reliably assembled with high quality and in large quantities, and to provide a stepper motor capable of reliable, precise high frequency step operation.

Another objective is imposed by the need in disc drive design to reduce the space occupied by the disc drive. Therefore, an objective herein is to provide a high frequency stepper motor that can be incorporated in a very small physical package.

A related objective herein is imposed by the constant requirement in the disc drive industry and especially the mass production disc drive industry to provide a highly reliable product at the lowest possible cost. Therefore, it is a specific objective to provide a stepper motor that can be reliably assembled at a relatively low cost. A related objective herein is to provide a stepper motor design incorporating construction features such that in the event of a necessity for reworking of the motor, such reworking can be easily done.

A further objective herein is to provide a high frequency stepper motor in which the alignment of the rotor and the stator can be consistently, reliably achieved even with the imposition of very precise tolerances.

A further and related objective herein is to provide a stepper motor for use in a disc drive which lends itself to a fully sealed design, to eliminate contamination in the head-disc assembly (HDA).

In summary, the encapsulated stepper motor of

this invention comprises a rotor and stator both mounted in a single housing (which may be a part of the base casting as described in the incorporated application) the bearings supporting the rotor for rotation within the housing both being located on the rotor shaft on the same side of the rotor adjacent one another, the opposite end of the single housing being covered with a sealed plastic cover. The lamination stack that forms the stator is piloted by machined surfaces into a high tolerance fit within the housing, and clamped in place with a simple wave washer snap ring combination.

In a preferred embodiment, the stator laminations are designed with a decagonally interrupted periphery which can be used without changing the area of the poles, and allow space for the wires to the poles to be lead out past the lamination stack.

These symmetrically arranged flats serve a more significant function during the fabrication of the stator stack. The final accuracy of the assembled motor is greatly influenced by the precision with which the stator stack matches the extremely accurate design. The stator is formed of a plurality of individual laminations, each manufactured with precision die stamping equipment from thin sheet stock. Even the most precisely made manufacturing die set will, however, have variations, due to unavoidable tolerance differences, from nominal ideal design dimensions. The symmetrically arranged flat surfaces allow each lamination, as it exits the stamping die, to be rotated one tenth of a revolution before it is stacked on the preceding piece, to distribute any dimensional errors radially around the stator stack, thus preventing a flaw in the fabrication tool from being propagated throughout the height of the stator stack. Further, a preferred embodiment comprises a sealing plastic cover provided with a special pressure finger to hold the wires running to the stator coils away from the sharp edges of the stack wave spring and snap ring; the cover is also specifically designed to capture the wires to relieve the strain on the wires.

In an alternative embodiment, where the bearings are located on opposite sides of the rotor, the stator is piloted into a precisely aligned position on an inner wall of the housing adjacent the front bearing, the other end of the stack being held in place by a bearing holder interposed between the rear bearing and the edge of the stator, the holding forces being precisely defined to accurately align the stator with the rotor of the stepper motor. In a preferred embodiment of this alternative, this bearing holder includes an annular groove filled with a silicon rubber or similar semi-compliant material to allow for thermal differential expansion of the surface of the bearing against the surface of the bearing holder as well as to damp out vibrations between the bearing and the stator.

The alignment of the rear bearing in the envelope of the single bell housing is preferably defined using a screw that is threaded into the inside of the shaft adjacent the rear bearing holder, or a ball that is swaged into an opening in the shaft to press the outer surface of the shaft tightly against the inner surface of the inner race of the bearing.

The entire assembly, including the rear bearing, bearing holder and stator support, as well as the stator is held together with a star-shaped spring comprising a plurality of fingers that slide into and rotate within slots in the housing in a bayonet arrangement. These slots allow insertion of the star-shaped spring under pressure, and rotation under pressure within the groove to a seated position. The same groove then accepts the encapsulating plastic cover, preferably inserted through the same openings as the bayonet arms of the spring, though being rotated in the opposite direction.

The following is a description of some specific embodiments of the invention, reference being made to the accompanying drawings, in which:

FIG 1 is a vertical sectional view of this invention, the section being along line B-B of FIG 4B;

FIG 2 is an expanded detail view of the portion of FIG 1 marked by the arrow B;

FIG 3 is an expanded detail view of the portion of FIG 1 marked by the arrow C;

FIGS 4A and 4B are bottom plan views of the encapsulated motor of this invention showing the relationship of the rotor, shaft and stator of the assembled motor;

FIG 5 is a vertical, sectional view of an alternative embodiment of the motor of FIG 1;

FIG 6 is a plan view of the spring retainer used to hold together the motor of FIGS 1 and 5;

FIG 7 is a bottom plan view of the motor of FIG 5;

FIG 8 is a vertical sectional view of a second alternative embodiment; and

FIG 9 is a vertical sectional view of a third alternative embodiment.

FIG 1 is a vertical section of the preferred embodiment of an encapsulated stepper motor disclosed and claimed herein. All the components of this stepper motor are mounted in a single machined housing 10, which could be cast and machined as an integral part of the base casting of the disc drive. The essential elements of the encapsulated motor of this design comprise the shaft 12 carrying a rotor 14, rotating past a stator 16 formed as a laminated stack. An end plan view of the stator 16 is shown in FIG 4A, where the laminated stack is shown to have an outer surface in the shape of an interrupted decagon. That is, the outer surface of

the stack has ten flat sides 18A-18J, so that the individual laminations that form the stack may be properly aligned. The flats of this ten-sided symmetrical figure are each opposite a pole 20A-J of the stator.

Windings 22A, B, C for each phase are wound on the stator poles 20. As appears clearly in the illustration of FIG 4B, each stator pole 20A-J has a winding 22A-C thereon for selective energization to cause rotation of the rotor 24. The end of each stator pole has a plurality of teeth 26 facing the rotor teeth 27, the number of stator teeth 26 and the pitch between the rotor and stator teeth effecting the total rotation of the rotor 24 for each step. An advantage herein is that clearance between the stator teeth 26 and the rotor teeth 27 is minimized because the rotor/stator tolerances are precise.

Returning to FIG 1, one can see that the stator sections are accurately aligned with rotor 14 by the insertion of a stator section 16 between internal and external cylindrical surfaces 30, 32 of the housing 10. In this way, the alignment between the stator stack 16 and the rotor 14 is maintained, while encompassing the stator 16 within a single housing envelope 10, rather than using a pair of end bells as is required by the prior art. It can also be seen, as will be discussed further below, that the lead wires 36 to the stator coils 22 are led out past one of the flat surfaces 18 of the stator so that the wires are not unduly crimped or stressed.

In the preferred embodiment of the present design shown in FIG 1, the rotor shaft 12 is supported by a pair of bearings 40, 42, both mounted within the housing 10 toward the same end of the rotor shaft 12 and on the opposite side of the rotor 14 from the encapsulating cap 44. In FIG 1, both ball bearings 40, 42 are shown guided into a single machined cylindrical opening 46 in the housing 10. The bearings are separated by a pair of Belleville springs 47, 48 arranged to establish a biasing force against the outer race of each bearing toward the outer ends of the shaft in order to maintain the alignment of the shaft. By using the single cylindrical opening 46 in the cast housing 10 and locating bearings 40, 42 side by side, the chances of misalignment of the rotor shaft are minimized. In contrast, where two end bells are used, construction of the motor incorporates two different pieces. The assembler of the motor must control the parallelism of the stack when it is inserted in the housing, and the concentricity of the front and rear end bells. This is a difficult task, entailing working with precision tolerances on a mass production level. This invention, by eliminating this problem, lends itself to mass production of high reliability stepper motors.

A further advantage of this design is that it is a sealed design—a requirement of disc drive manu-

facturers. The seal is accomplished in part by providing that the upper bearing 40 of the bearing pair whose top surface is flush with the upper surface of the housing includes an integral bearing seal. The open end of the housing below the rotor 14 and stator 16 and on the opposite side of the rotor from the bearings is covered with a plastic, snap-on cap 44 that covers the housing 10 below the end of the shaft 12. The advantage of incorporating the snap-on cap 44 is that if rework of the motor becomes necessary, the cap can be easily snapped off. Typically, a slot can be provided in the cap 44 which can be engaged by a screw driver to snap the cap off the housing.

As shown in detail in FIG 2, identified by arrow E in FIG 1, the lower portion of the housing 10 includes a flange 50 having a circumferential groove 52. The circumferential groove 52 receives a circumferential protrusion 54 carried on the cap 44, which protrusion 54 is pressure fit or snapped into the groove to hold the cap in place.

FIG 3, which is the detail identified by arrow C in FIG 1, illustrates a different section through the cap 44 and housing 10. Specifically, FIG 3 illustrates incorporation of a strain relief 56 to reduce the strain on the ribbon cable 36. A tongue 56, provided to function as this strain relief is defined in the upper end of the cap 44, which pushes the cable 36 up into a pocket 58 in the housing 10 in a limited region of the housing 10 where the flange 50 shown in FIG 2 is not present. By pushing this tongue 56 against the cable 36, the cable is deformed and captured tightly between the elastic cap 44 and the housing 10, insuring that no undue strain can be conveyed from the wires as they run through the housing back to the coils 22. Just inside the strain relief tongue 56, an extended finger 60 is provided reaching up from the top surface 62 of the cap 44 to contact and press against the ribbon cable 36. This elastic finger 60 is provided so that its distal end 64 contacts the ribbon cable 36 in an area adjacent to the wave washer 66 and snap ring 68 which are used to hold the stator laminations 16 in place. In this way, the ribbon cable is biased away from and kept out of contact with the wave washer 66 and snap ring 68, both of which have sharp edges which could cut or damage the cable 36.

It should be noted here that the cable 36 is routed between the machined inner surface (32 in FIG 1) of housing 10, and one of the flat surfaces (18A-J in FIG 4) on the outside of the stator 16 in opening 69 shown here.

Several other features and advantages will become apparent by consideration of the assembly of the invention. For example, a classic problem in the assembly of a motor of this type is keeping the stator concentric with the rotor for free and clear

rotation of the rotor relative to the stator.

Referring again to FIG 1, the stator 16 is piloted on a machined cylindrical internal surface 30 into the housing 10, as well as a machined cylindrical internal surface 32 which defines a portion of the outer upright wall of the housing 10. These housing surfaces are machined so that the surfaces, and especially the surface 30, are very concentric with the surface 70 that defines the position of the bearings 40, 42. In this way, the tolerances at the inside diameter of the stator 16 can be set to very closely match the machine surfaces, so that when the stator 16 is inserted, it centers itself on the piloting surface 30. This is significant in the assembly of the motor of this invention, as the design is defined by very small air gaps between the stator 16 and the rotor 14. The shaft 12 itself is centered by the bearings 40, 42 which are, as explained above, precisely located by the cylindrical surface 70 defining the edge of the common bearing bore in the housing 10. The rounded corner 72 at the base of the cylindrical piloting surface 30 allows the stator stack 16 to be pressed into position and rest on the cylindrical surface 30.

A further advantage of this design is that because of the minimal tolerances, the bearings 40, 42 can be inserted in place using a 4-surface lock. That is, inner surfaces 74, 76 of the inner races, and outer surfaces 78, 80 of the outer races of the bearings 40, 42 are locked to the shaft 12 and housing 10, even though the bearings 40, 42 and housing 10 may be made of dissimilar materials. This design can be adopted, leading to further manufacturing economies, because the center-to-center distance of the two bearings 40, 42 is so small as opposed to known designs wherein one bearing is located on each end of the motor.

In assembling the motor, the shaft 12, before its placement in the housing 10, has the rotor tooth segments 82, 84, separated by spacer 85, placed thereon with the teeth of the rotor segments 82, 84 precisely aligned 180° out of phase. Then the shaft 12 is placed in the housing 10 and the bearings 40, 42, together with the loading Belleville springs 47 and 48, are locked in place either by adhesive or by shrink fitting. When the adhesive is cured or the temperature differential withdrawn, the Belleville springs 47, 48 will define the permanent diverging preload force factors of the bearings 40, 42. At this point, the pulley 90 incorporating pins 92, 94 used to attach the pulley to a typical band of an actuator in a disc drive is press fitted on the end of the shaft. Prior to this step, if the bearing 40 is a magnetic bearing, the magnetic fluid is inserted. With the pressing on of the pulley, a very concentric rotor assembly is achieved. One should note that this assembly makes use of a rotor shaft which does not have any steps, i.e., a single diam-

eter rotor shaft.

With completion of the rotor assembly, the stator 16 can now be inserted in place, piloted against the cylindrical surface 30 for precise location relative to the rotor 14, and resting against the machined surface 96 to maintain the stator lamination stack 16 perpendicular to the central bore. A plastic bobbin 98 is used to help hold the stator 16 in place, although the primary closure mechanism is the wave washer 66 and the circular retaining ring 68 (FIG 4B) that snaps into place in the machined annular channel 100 of housing flange 50. The wires 36 to the coils are led out through a special wiring channel provided by one of the flat surfaces 18 adjacent to this portion of the housing 10 adjacent to the stator stack 16. It should be noted from FIG 1 that the teeth of the stator extends beyond the area of rotor 14/stator 16 interface to provide piloting on the cylindrical surface 30. FIG 4B also helps illustrate the means for holding the stator stack 16 in place in the housing 10. Typically, the means of stator attachment is to simply glue it in place. In this embodiment, the stator stack is retained under tension with the wave washer 66 held in place using a snap ring 68 which is fitted into a machined annular channel 100 in the housing flange 50. The snap ring 68 includes eye holes (one is shown as 102) which can be used to compress the diameter of the snap ring to press it against the wave washer and into the machined annular channel 100, while leaving an opening in the snap ring through which the coil wires 36 can be passed.

FIG 5 shows an alternative embodiment of a stepper motor using a single housing to hold all the elements of the stepper motor. In the embodiment of FIG 5, the housing 70 incorporates a structure in which the shaft 12 is supported for rotation by front and rear bearings 104, 106, respectively. These bearings 104, 106 straddle the rotor indicated generally at 14. In such an arrangement, it is important to note that a primary achievement in this invention is combining the two ball bearings 104, 106 in the single housing 10, although the front and rear bearings 104, 106 are located on opposite sides of the rotor 14. In contrast to the prior art wherein two separate end bells were screwed together or otherwise attached to form the motor housing which supports the stack of stator laminations 16, in this invention a unique method of supporting the stator stack 16 is provided within the single housing envelope 10. This prevents skewing of the rotor 14 relative to the stator 16, a common deficiency of the prior art.

Of critical importance to present design in achieving alignment of stator 16 and rotor 14 is the piloting of the stator stack 16 at its front undercorner on the front inner wall portion 110 of the

housing 10. The right, or outer front portion 112 of the stator 16 rests against a machined circumferential surface 114 of the housing 10. Finally, the rear bearing holder 116 also pilots against the rear inner edge 118 of the stator 16. In this way, opposing forces represented by the arrows 119, 120 are set up on the outer front and inner rear portions of the stator stack. These forces 119, 120 combine with the piloting effect of the facing surfaces 109, 110 to forcibly and positively align the stator stack 16 in the housing 10.

In an alternative embodiment, the recessed region 121 above the front inner corner 109 of the stator stack could be filled in as shown on the left of FIG 5, forming machined circumferential surface 115 which will support the stator 16 at its front inner corner 109. As a consequence, the machined circumferential surface 114 could be eliminated as also shown at the left side of FIG 5 at 117, as the force indicated by arrow 120 necessary to balance the force indicated at arrow 119 could now be balanced by a new force which is created at the filled-in shoulder as indicated by the arrow 122.

Another significant element of this embodiment is the rear ball bearing holder 116, and manner in which it supports the stator 16 in place and is in turn cooperatively supported with the rear bearing 106 which is supporting the shaft 12. As a preliminary matter, it is important in this and the following embodiments that the rear bearing support 116 be of a non-magnetic material. This is important because it is located close to both the stator 16 and the rotor 14. If the rear bearing support 116 were of magnetic material, it could have a negative effect on the magnetic fields created during operation of the motor, and thereby negatively influence the positioning of motor. The same is true of the housing 10 which supports the motor structure. It is also important to select the material of the housing 10 and rear bearing support 116 to have a thermal coefficient of expansion as close as possible to that of the material of the stator 16. In this way, the disc drive and motor can be operated over the full defined temperature range for which a disc drive must be useful, without negative effects on the performance of the motor due to stator misalignment. This balanced thermal expansion is also important because of the fact that the stator 16 and housing 10 are effectively piloted on a relatively small surface using this rear bearing holder 116.

A further significant feature of this invention is the provision of an annular channel 124 in rear bearing holder 116 surrounding the rear bearing and filled with a silicon rubber material. The purpose of providing this annular channel 124 filled with a resilient material is to perform two functions. First, this allows for differential thermal expansion of the outer surface of the rear bearing of the motor

relative to the rest of the motor. This is important because in the present design, all elements of the motor are effectively mechanically coupled, whereby a differential expansion of this outer surface could result in a modification of the alignment of the stator 16 relative to the rotor 14. Further, the provision of this resilient material constrains the outer bearing surface such that any vibrations that may occur in the rear bearing are damped out rather than being transmitted through the bearing support 116 to the remaining elements and specifically the stator of the motor.

The entire motor is assembled using a unique preload arrangement that relies in part on a snap ring 126 inserted in an annular channel 128 in the front portion of the shaft 12 at the front of the housing. This snap ring 126 is used to restrain the position of a sleeve 130 which in turn is pressed against the inner race 132 of front ball bearing 104. This ball bearing 104 is supported and locked in place between the shaft 12 and an inner surface 136 of the housing 10. This snap ring 126 and sleeve 130 arrangement is combined with a dead weight mechanism to achieve desired preload in this system. This preload is achieved by positioning the inner race 138 of lower bearing 106 using a sleeve or washer 140 which presses against the lower surface of the inner race 138 of that bearing 106. The appropriate tension to define the preload is achieved by providing a pair of Belleville springs 141, 142 at the upper surface of the rear bearing 106, the ends of the upper Belleville springs 142 in turn pressing against the bearing support 116, whereby a mechanical coupling is achieved through the piloted stator 116 and housing 10. The preload is locked in place with a screw 144 which is threaded and seated in a bore 146 internal to the shaft 12. Positioning of the screw 144 by threading it in an appropriate selected depth forms a DB configuration of a type known in this technology which effectively defines diverging forces from the rotor toward the ends of the shaft to provide a highly stable drive shaft for the stepper motor. In this configuration, the outer races 147, 148 of the rear and front bearings 104, 106 are effectively forced away from each other and biased toward points on the shaft axis beyond the ends of the shaft, providing an extended effective area of the biasing force to stabilize the shaft 12 as defined above. Of course, the Belleville springs 141, 142 can be replaced by other known resilient means such as wave washers the like that can provide the proper force distribution between two facing as required. This extended effective region is achieved by providing a contact point of the inner races against the shaft, while the contact point of the bearing support and spring is against the outer races. The lines of force indicating contact of the

bearing balls with inner and outer races appear to extend from a point adjacent the outside of rotor 14 which is near the center of the shaft extending inward toward the outer ends of the shaft 12, as indicated by arrows 144.

As a means of holding this motor together under appropriate tension and minimizing the possibility of movement of the parts while allowing for ease of assembly and access to the interior of the motor, a star-shaped spring 150 is provided shown in cross section in its assembled form in FIG 5, in a plan view in FIG 6, and as it appears inserted in housing 10 in FIG 7. As clearly appears in the plan view of FIG 6, the star-shaped spring 150 includes a central framing portion 154 having an opening at the center thereof 152, where the spring may be fitted over the shaft 12 and outer race 147 of the rear bearing 106 or directly over the rear bearing support 116 as shown in FIG 5. Thus, the framing portion 154 of the star-shaped spring 150 biases the rear bearing support 116 up against the rear of the stator 16 along the line of force 119 discussed above to aid in maintaining the position and piloting of the stator 16 within the housing 10. A plurality of fingers 156A-D are provided which, as appears most clearly in FIG 7, are inserted in notches 158A-D in the outer edge of the housing 10, the notches 158A-D opening into an annular channel 180. After insertion, the fingers 156A-D may be rotated through the annular channel 180 in the lower portion of the housing 10 to be seated in a position from which they cannot be easily disturbed. The star-shaped spring is made of a spring-like material such as a high tensile stainless steel in order to provide a considerable tensile force that will last over a long term upward against the bearing and stator support 116.

In summary, the star spring of FIGS 6-7 allows all the elements of this invention to be constrained and maintain a constant relative relationship without the use of screws. This is important, as screws can be tightened with variation, they are additional parts to handle, and therefore, add additional cost both in terms of materials and assembly time. Also, removal and reinsertion of screws during any needed rework can generate undesirable particulate contamination. Their elimination is clearly highly desirable. The cover 170 appears in sectional form in FIG 5 and can be seen inserted and closed in the housing in FIG 7. The edges of the cover are defined by the line indicated at 171. This cover completely covers and seals the housing against the entry of dirt. The cover also includes four fingers 172A-D which are inserted through the same notches 158A-D as the fingers 156A-D. After insertion, they may be rotated, preferably in the same direction as the bayonet fingers 156A-D of the star-shaped spring 150 are rotated. Thus, the

cover is seated behind the star spring 150 in the housing annular channel 180, and prevents the spring 150 from moving due to vibration or the like back toward the entry notches 158A-D.

It should also be noted that it is important that the sleeve 130 which is used to position the front bearing 104 be hermetically sealed against the shaft 12, and that the magnetic seal 180 be sealed at its outer edge against the housing 10 to maintain the integrity of the entire system.

The embodiment of FIG 5 comprises a dual pole magnetic seal 180 affixed at one end typically by an adhesive to the housing 10, the other end being separated by a narrow gap 182 from the magnetic material of the spacer 130. This gap 182 is filled with a ferro-fluidic magnetic material to form the magnetic seal and close the magnetic path. It should be noted that since the shaft 12 is of a non magnetic material, it is essential to provide a sleeve 130 rotating with the shaft and the inner race of the bearing to close the magnetic path. As can be seen, the magnetic path closes upon itself in this embodiment, with path generally being traced from one end plate 184 through the magnetic seal and the sleeve 130 to the other end plate 186. It would be possible to replace the embodiment shown herein with a magnetic seal comprising solely a magnetic piece without pole pieces, wherein the seal relies on fringing fields for the magnetic effect.

FIGS 8-9 illustrate further alternative embodiments hereof, and specifically of the rear bearing support holder and means for defining the preload in the motor. In FIG 8, the rear ball bearing support 200 is smaller than that shown in previous embodiments, although it is still fitted between the rear ball bearing 202 and the stator 16 to support the stator 16 in place. The inner corner 217 of the rear bearing support 200 is ground concentric with the rear bearing 202 and the outer corner 218 concentric with the stator laminations 16 in order to support the corner edge of the stator laminations. Note that the rear ball bearing support 200 and the rear bearing 202 must be separate pieces, as known bearing materials are magnetic, while the rear bearing support is non-magnetic.

Highly efficient approaches to fixing the preload in the motor can be seen illustrated in FIGS 8-9. Referring to FIG 9, assuming the base of the shaft 206 can be supported, and further assuming that the inner race 208 of the front bearing 136 is already glued in place, and further assuming that the outer race 210 of the front bearing is also pressed in place, then by placing a holding force against the combination rear bearing 202 and stator support 200, using the star spring of FIG 7 or an equivalent approach, then the inner race 212 of the rear bearing 214, which is a sliding fit on the shaft

12 can be placed. Then a ball 216 which is of an appropriate size relative to the hole 218 in the shaft can slide into place. This ball is swaged or pressed into place. This swaging operation using the sphere 216 locks the preload in place by fixing the inner race of the rear bearing against the shaft. This assembly is accomplished with a dead weight force against the inner race 212 of the rear bearing which effectively forces this inner race against the outer surface of the shaft while the sphere is being wedged in place.

In the embodiment shown in FIG 9, a metallic Belleville spring 218 is added surrounding the base of the shaft 21 and beneath the inner race 212 of the rear bearing in order to provide additional support to this bearing. These springs are held in place by the base of the screw 206 which is threaded into the bottom of the shaft as has previously been explained. It should also be noted that the bearing and stator support 200 in this embodiment includes a pair of metallic elements 223, 225 lining the machined grooves which abut the stator 16 and rear bearing 42. These elements 223, 225 which are magnetic but non-conductive, support the spindle holder and give it added rigidity.

The inclined plate 218 constitutes the modified metallic Belleville spring which provides the desired DB preload. As can be seen, the spring force is inserted against the outer end of the rear inner bearing race 212, creating the required diverging forces along the length of the shaft 21. FIG 8 also clearly shows the location of the star-shaped spring 150 which is used to bias the stator support into engagement with the stator.

The structure, features and advantages of this invention have been described above. Alternatives to the scope of this invention may become apparent to a person of skill in the art who studies this invention disclosure. Therefore, the scope of this invention is to be limited only by the following claims.

## Claims

1. An encapsulated stepper motor comprising a single housing bell for supporting the elements of said motor, said housing comprising a single end wall and a cylindrical side wall, a support shaft mounted for rotation in said housing end wall, a rotor of said motor being mounted for rotation with said shaft in said housing bell, a stator fixedly mounted in said housing and having a plurality of coils wound thereon, selective activation of said coil causing step-by-step rotation of said rotor,

and bearing means mounted only on one side of said rotor between said rotor and said housing end wall to support said rotor for said selective rotation.

2. An encapsulated stepper motor as in Claim 1 wherein said cylindrical side wall of said housing is jointed to said end wall at one end and is open at the other end, and including a plastic cover press fitted over said open end of said side wall to seal the region enclosed by said housing against contamination.

3. An encapsulated stepper motor as in Claim 2 wherein said open end of said side wall includes a flange having a matching recess on the inside thereof, said plastic cover including a lip adapted to fit within said recess to enclose said opening.

4. An encapsulated stepper motor as in Claim 1 wherein said stator includes inner and outer circumferential surfaces and said housing includes internal planar surfaces adapted to guide said stator into a predetermined position in said housing and hold said stator in said position.

5. An encapsulated stepper motor as in Claim 2 including a plurality of control wires connected to said coils for selectively energizing said coils, said wires being led out of said housing bell between the open end of said bell and said cover, wherein said plastic cover comprises a finger extending above said cover against said housing to hold said wires against said housing.

6. An encapsulated stepper motor as in Claim 5 wherein the outer surface of said stator defines a regular decagon, said control wires being lead between the circular interior wall of said housing and the surface of said decagon.

7. An encapsulated stepper motor as in Claim 6 wherein said flange of said side wall is interrupted by a wire channel for leading said control wires out of said housing, said finger being located adjacent said channel.

8. An encapsulated stepper motor as in Claim 4 including spring means located at the base of said stator above the opening for said cap for biasing the stator into said predetermined position in said housing.

9. An encapsulated stepper motor as in Claim 8 wherein housing comprises a groove defined in said flange, said spring means comprising an elastic member located below said stator for urging said stator into position, and a snap ring held-biased in said groove for holding said flexible member in position.

10. An encapsulated stepper motor as in Claim 9 wherein said flexible member comprises a wave washer supported against a shelf below said stator by said snap ring.

11. An encapsulated stepper motor as in Claim 9 wherein said cylindrical side wall of said housing is jointed to said end wall at one end and is open

at the other end, and including a plastic cover press fitted over said open end of said side wall to seal the region enclosed by said housing against contamination.

12. An encapsulated stepper motor as in Claim 11 wherein said open end of said side wall includes a flange having a matching recess on the inside thereof, said plastic cover including a lip adapted to fit within said recess to enclose said opening.

13. An encapsulated stepper motor as in Claim 11 including a plurality of control wires connected to said coils for selectively energizing said coils, said wires being lead out of said housing bell between the open end of said bell and said cover, wherein said plastic cover comprises a finger extending above said cover against said housing to hold said wires against said housing.

14. An encapsulated stepper motor as in Claim 13 wherein the outer surface of said stator defines a regular decagon, said control wires being lead between the circular interior wall of said housing and the surface of said decagon.

15. An encapsulated stepper motor as in Claim 7 wherein said flange of said side wall is interrupted by a wire channel for leading said control wires out of said housing, said finger being located adjacent said channel.

16. An encapsulated stepper motor as in Claim 10 wherein said rotor shaft has an unstepped, constant diameter shaft, said motor including a pulley pressed on said shaft outside said housing on the same side of said rotor as said bearings.

17. An encapsulated stepper motor as in Claim 16 wherein said bearings are locked between said housing and said shaft for supporting said shaft between said pulley and said rotor.

18. An encapsulated stepper motor comprising a single housing bell for supporting the elements of said motor, said housing comprising a single end wall and a cylindrical side wall,

a support shaft mounted for rotation in said housing end wall,

a rotor of said motor being mounted for rotation with said shaft in said housing bell,

a stator fixedly mounted in said housing and having a plurality of coils wound thereon, selective activation of said coil causing step-by-step rotation of said rotor.

front and rear bearing means mounted on either side of said rotor to support said rotor for said selective rotation in response to energization of said stator coils.

means for supporting said rear bearing on said shaft, and

means between said stator and said rear bearing for positioning said rotor relative to said bearing and said rotor and thereby defining a close tolerance relationship of the elements of said motor.

19. An encapsulated stepper motor as in Claim 18 wherein said stator includes inner and outer circumferential surfaces and said housing includes an internal planar piloting surface adapted to guide said stator into a predetermined position in said housing, said stator being held in said position by said piloting surface and said means for positioning said stator.

20. An encapsulated stepper motor as in Claim 19 wherein said means for positioning the stator comprise an annular non-magnetic support having a groove for piloting said stator on said support, whereby said stator is closely aligned with said rotor by the piloting effect of said housing and said support.

21. An encapsulated stepper motor as in Claim 20 including a star-shaped spring aligned with said rear bearing and said bearing holder to support said bearing, said holder and said stator in aligned relationship in said housing.

22. An encapsulated stepper motor as in Claim 21 wherein said star-shaped spring includes a central portion comprising a ring-like section and a plurality of fingers extending radially from said central portion, said housing comprising an annular groove cooperating with said radial fingers to capture said spring and restrain the elements of said motor.

23. An encapsulated stepper motor as in Claim 22 wherein said housing includes a plurality of openings allowing entry of the ends of said radial fingers, rotation of said spring relative to said housing capturing said spring in said groove and thereby the elements of said motor in aligned relationship in said housing.

24. An encapsulated stepper motor as in Claim 23 including a cover for said encapsulated motor having a plurality of prongs located in spaced positions on said cover to be inserted in said groove in said housing, whereby said cover is captured in said groove to seal said motor against the environment.

25. An encapsulated stepper motor as in Claim 24 including means for capturing said rear bearing in said housing comprising an open sleeve extending up the center of said shaft, and a ball wedged into said sleeve adjacent to said rear bearing, the pressure of said ball against the outer surface of said sleeve and the inner race of said rear bearing positioning said rear bearing on said shaft.

26. An encapsulated stepper motor as in Claim 19 wherein said bearing support includes an annular groove in the side of said support adjacent the outer race of said rear bearing, said groove including an annular ring-like form held in said groove and pressed between said rear bearing and said bearing support to damp out vibrations of said

motor and allow for differential thermal expansion of said bearing and said bearing support.

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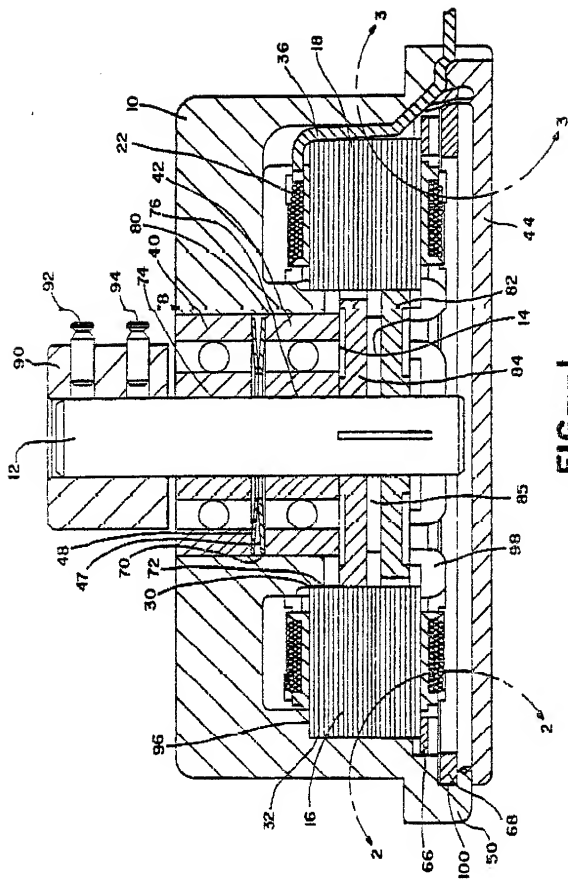


FIG. 1

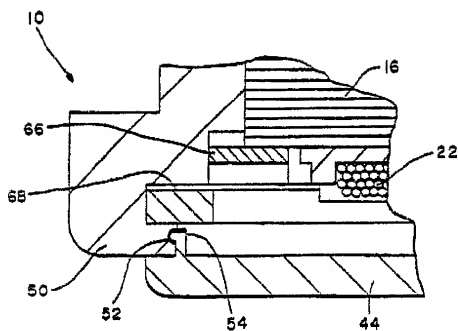


FIG.—2

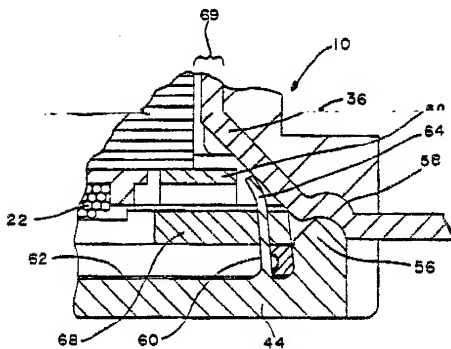


FIG.—3

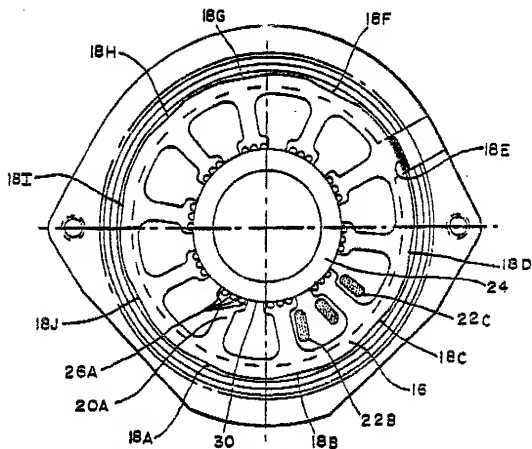


FIG.—4A

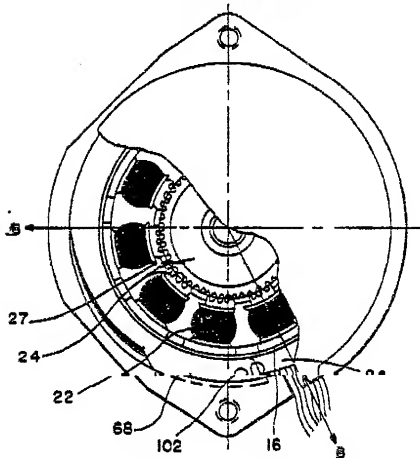
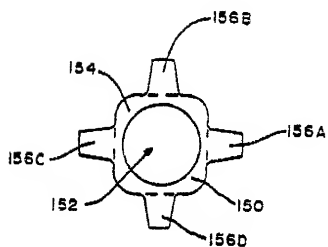
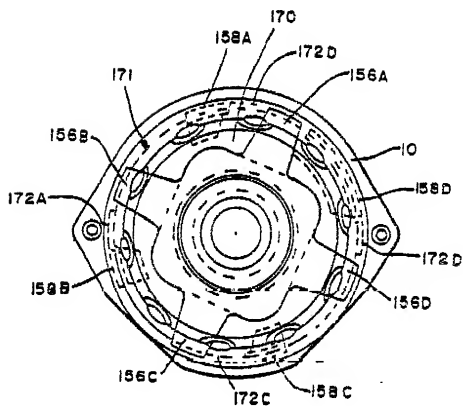


FIG.—4B





**FIG.—6**



**FIG.—7**

FIG.—8

